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ABSTRACT

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In contrast to steam turbines and gas turbines, the exhaust gas turbine operates not under conditions of steady flow, but under conditions of pulsating flow. With experiments, the author was able to show that it is possible to use the characteristic curves for continuous flow as boundary conditions for the operational behavior of the exhaust gas turbine. (MTB, January 1964, "Performance of Exhaust Gas Turbocharger Under Pulsating Flow". Excerpts in MTZ, 1964, Issue No. 9, pp. 364.) In the present report, various problems under conditions of continuous flow are treated that are of importance for the exhaust gas turbine. /29*

Author

1. Profile Loss

Due to the pulsating load, the relative entrance velocity and the entrance angle change very strongly over one revolution of the motor, in the case of the exhaust gas turbine. For this reason, strong separation would occur at the entrance edge of a blade which has a small radius.

* Note: Numbers in the margin indicate pagination in the original foreign text.

After extensive experiments in the wind tunnel, the M. F. profile (Mitsubishi wing) was developed especially for exhaust gas turbines. It has an entrance edge that is strongly rounded off and is, therefore, to a high degree insensitive against changes of the entrance angle. In an experiment we were able to determine that the pressure loss in the M. F. profile is considerably smaller than in an older blade profile used for steam turbines. The smaller pressure loss can be attributed to the gradual velocity change at the blade exit (Figure 1).

Because the exit angle from the blade influences the turbine efficiency, it is very important to determine it exactly. One of the methods of determining it, the "opening by pitch theory," was evaluated by the author and was substantiated by experimental results. The differences between the results calculated by the theory and those obtained experimentally were smaller than 0.5 degrees.

2. The Secondary Flow Loss

The loss is strongly influenced by the side ratio of the blade. This is defined as the blade heighth to its length, SV = H/ℓ.

From the pressure measurements it can be seen, that in the vicinity of the blade limit, a strong vortex is created, which does not influence the flow through the central blade region for large side ratios ($H/\ell > 2$). This influence is very noticeable for a $H/\ell < 1$. This fact influences the pressure loss, which is composed of profile loss and secondary flow loss. The total pressure loss increases with decreasing side ratio, and the increase for a side ratio < 1 is larger than for $H/\ell > 1$.

In contrast to the blade in motion, no vortex can be seen in the nozzle. According to the secondary flow theory, the pressure loss in the nozzle would be small compared to that across the blade in motion. However, the experiment in the wind tunnel shows that the loss due to secondary flow in the nozzle is only slightly lower than that of the blade.

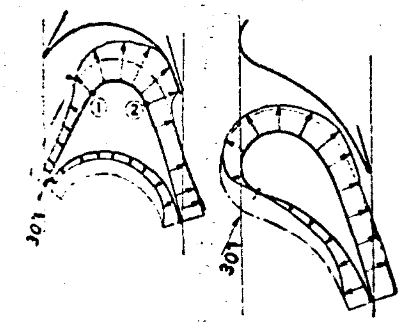

Figure 1

Pressure Distribution Accross Blade Profiles.
Left: older profile; Right: M. F. Profile

3. Results With the Air Turbine

In addition to the fundamental investigations of blades and nozzles in the grid wind tunnel, we also investigated a turbine driven with compressed air, which was coupled to a 25-horsepower dynamoter. With this apparatus, all operational states of a non-continuously loaded exhaust gas turbine (i.e., variable flow rate from G'_{max} to $G' = 0$) were investigated for constant speed of revolution. We recorded performance, pressure ratio and efficiency. (Figure 2).

From the point at which the flow rate is largest to a certain smaller value, the turbine performance and η_T are positive. If the flow rate is decreased further, it is necessary, in order to keep the speed of revolution constant, to use power to drive the turbine, even though the pressure

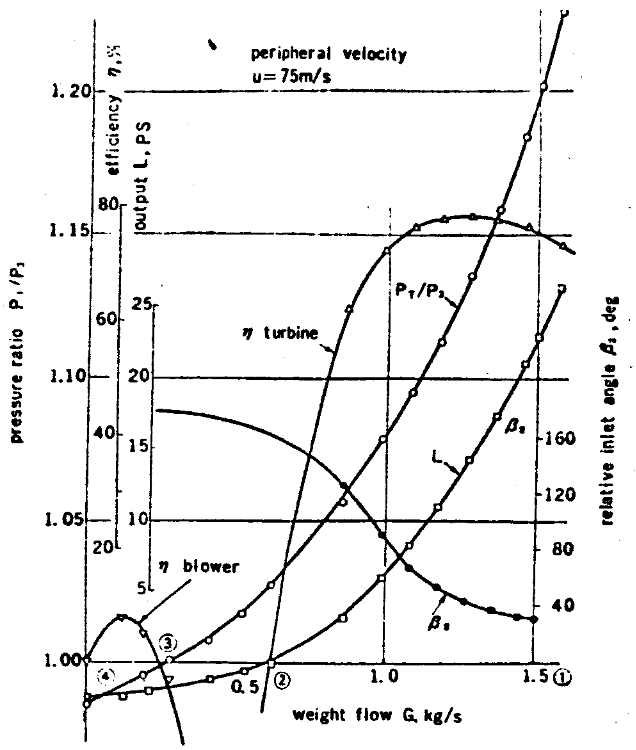

Figure 2

Experimental Results for the Air Turbine with Blades
in the Shape of the M. F. Profile.

ratio is larger than 1. In this region the apparatus works neither as a turbine nor as a charger. The pressure ratio becomes smaller than 1 only when the G' decreases further. The wheel then acts as a charger until the flow rate 0 is attained.

The exhaust gas turbine operating with a pulsating load can work in any region. It is desirable to have a good "load ratio" of the turbine wheel, because due to the mass inertia of the movable part, the exhaust gas is drawn off during the flushing. This accelerates the flushing process.

Due to the insensitivity to changes of the entrance angle, the M. F. profile described in Section 1 guarantees good charger performance.

Further experiments were carried out to investigate the turbine efficiency for different speeds of revolution and to partition the losses. In addition to the fully loaded turbine, such as is the case for numbers of cylinders that are divisible by three, we also investigated the turbine /30 which was partially loaded. The partial loading was obtained with two gas intakes, the surfaces of which were changed. In the case where one entrance was completely closed and the flow rate in the other entrance was varied, we obtained a performance maximum that was 17 percent lower than for the totally loaded turbine.

4. Behavior for High Velocities

As the motor performances are increased, the pressure in front of the exhaust gas turbine increases also, as well as the velocity of the gas flowing through the blade. The flow states in nozzles and blades were photographed for the Mach numbers from 0.6 to 1.1, using the interferometer method and the Schlieren methods. The results were evaluated.

We found that the lowest pressure and, therefore, the highest velocity does not appear at the smallest cross section of the nozzle, but further downstream, some distance away. Due to this phenomenon, the actual volume flow rate is smaller than the calculated one. In the present experiments, the difference between the calculated amount and the measured amount was 6 percent.

If the Mach number approaches the value 1, a shock wave appears at the nozzle exit. The exit angle becomes larger and the boundary layer begins to separate from the nozzle (Figure 3). The losses increase strongly beginning with $M = 0.7$ and reach a maximum for $M = 1$. If the Mach number is increased further, the total loss calculated from the pressure distribution, as well as the exit angle β_2, decrease again.

The appearance of the shock wave, the frequency of which should lie between 1,000 and 3,000 cycles, induces the blade to carry out oscillations due to the pressure change which is caused, which leads to resonance and to failures. In the report, the formation of the shock wave is discussed in detail.

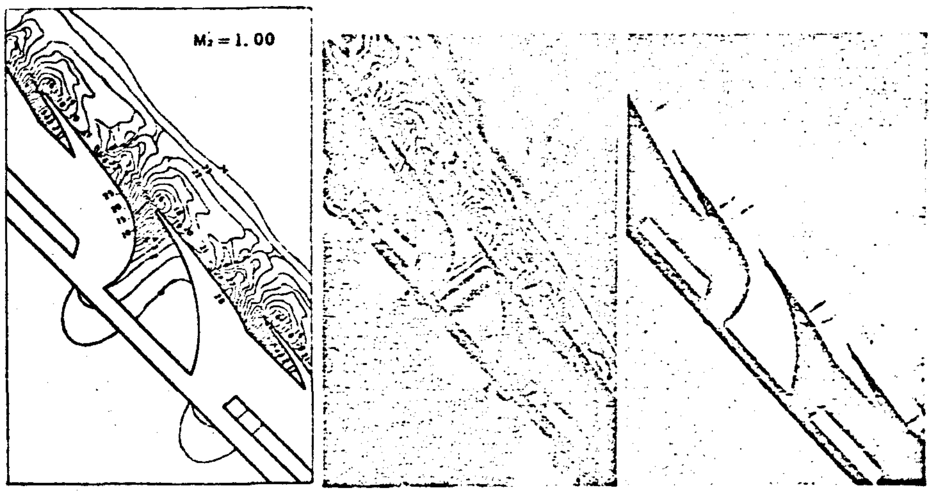

Figure 3

Flow Conditions in the Nozzle. Theoretical Mach Number at the Exit $M'_2 = 1.0$. (Obtained according to the interferometer method and the Schlieren method.)

In Appendix 1, two methods for the evaluation of experiments in the grid wind tunnel are discussed.

Appendix 2 contains details on experiments with high velocities. The optical apparatus is described, which was used for the photographs with the interferometer method and the Schlieren method. The interesting values were calculated from the photographs obtained using the equations given. [8305]

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